CHAPTER 3

MATERIALS PROBLEMS AND CONSTRUCTION PROBLEMS

3-1. General. The primary desired attribute of large-stone materials is intrinsic durability against weathering and other environmental influences. Even those materials buried under other zones are expected to remain strong and to resist effectively any degradation. Otherwise, portions of the mass may suffer damaging settlement, slippage, or alteration of subsurface drainage. To be durable, the material must resist several natural and man-induced disturbances. Table 3-1 lists most of these in three categories: design-related, material-related, and external factors. Clearly, there are numerous factors, not necessarily related to material, which can cause performance problems. The range of problems is increased even further by considering the economics of producing large stone. An extensive review of CE experience in large-stone construction (Evaluation of Quality and Performance of Stone as Riprap or Armor) constitutes the basis of the summary of the numerous problematic factors discussed below.

Table 3-1. Factors Affecting Performance of Large-Stone Materials*

Design-Related Factors	Material-Related Factors	External Factors
Current dislodgment	Sediment abrasion	Snow cover
Wave dislodgment	Rocking abrasion	Ice-block thrust
Flood crest	Water corrosivity	Ice-block rocking
Storm surge	Air corrosivity	Ice cementation
Void plugging	Freezing	Floating debris
Drainage reduction	Freeze-thaw cycling	Root growth
Undercutting	Wetting	Incidental humans
Rapid drawdown	Wet-dry cycling	Vandalism
Rapid filling	Heating	Sedimentation

*Excluding foundation deficiencies.

3-2. Supply Limitations. Economic factors associated with supply are potentially the most important influences on construction with large stone. Large stone is generally scarce and costly to produce and usually commands a premium price. Fortunately, the cost factors can be evaluated with confidence by experienced personnel. Some major aspects of the economics of obtaining and using large stone are summarized below.

a. Production Constraints. Several production characteristics of a source or quarry operation are capable of affecting its suitability in providing the needed stone.

(1) Product Mix. Large stone material is commonly separated as a by-product in quarries mainly operated for aggregate or industrial limestone such as for flux. Two problems can arise. The production of large stone may only constitute a few percent, and unless the demand for aggregate is immense, the stockpile will be depleted and the weekly production may fall short of large-stone needs of the project. Elsewhere, in contrast, the large-stone demand may exceed demand for aggregate and lead to an increasingly large accumulation of unmarketable small rock wasted in the quarry. A burden such as this on the operator occasionally affects the CE project work.

(2) Quarrying Method. Problems with quarrying methods frequently center on the use of large charges in blasting patterns designed for fragmentation. Heavy blasting produces incipient cracks in previously solid large stones but is considered beneficial toward producing a small-size product like aggregate. The needs for crushing and secondary blasting are reduced. Heavy fragmentation also facilitates the handling of material. Damage is commonly expected in large stone coming from small-stone operations, and some CE offices contractually avoid, discourage, or prohibit heavy blasting where large stone is to be produced.

(3) Reserves. Reserves quantify not only the amount of large-stone material available in situ, but also the distribution of that material. Obviously, reserves must exceed the amount of stone required plus an extra increment for wastage or there will be a shortfall. Generally, the problems will be greater in producing large individual stones dispersed throughout a quarry than where the large stones are concentrated in a small, accessible area or ledge. Problems of detrimental mixing of material types can also impact peripherally where large stone of marginal quality is intimately mixed with superior stone.

(4) Operational Status. The evaluation of the capacity and quality of an operating stone source is fairly straightforward. Commercial operators are willing to share technical data on operational conditions and proven resources. Frequently, however, it is necessary to consider producing stone from inactive or undeveloped sources including those where proven reserves have been exhausted and only unexplored ground remains. Careful geological investigations (Chapter 4) are required to avoid risking a serious shortfall or quality problem.

b. <u>Transportation</u>. The transportation of material commonly constitutes the largest single economic factor in procurement of large stone for construction. Even where suitable stone is abundant in the immediate region, a distinct advantage goes to the source with lowest transportation cost.

(1) Distance. Distance from source to the project site translates into mileage cost. Choice of mode of transportation and suitability of stone are complicating aspects that must be evaluated in coordination with distance. In some instances, the closest source has been used after testing marginally in engineering properties, only to find that the stone has been ineffective in service. Transportation cost does not always preclude distant sources; stone has been shipped hundreds of miles competitively.

(2) Mode. The mode of transportation is often more critical than the distance. Truck haulage is usually most costly, and truck hauls exceeding

about 25 miles (one way) should be viewed as potentially unfeasible unless other modes of transportation are lacking. Barge transportation has a cost advantage and is usually preferred where it is feasible. Rail haulage may have the advantage for long distances when barging is not feasible.

(3) Handling. Transportation handling refers to all efforts and associated costs following loading of material at the source and preceding unloading at the jobsite. Handling costs of this type are negligible where the stone is loaded on trucks at the quarry face or processing plant and dumped later at the job within reach of the placement equipment. Obviously, a change in mode of transportation adds increments of handling, with additions of cost. Stockpiling may also add substantial costs. It has also been perceived on some past stone work that increased handling tends to damage the material.

3-3. Government-Land Sources. The source of stone may be limited to locations on Government land adjacent to the construction site or to required excavation removed in the course of excavation for a project feature such as an emergency spillway. This choice is highly cost-effective but often reduces the quality of stone to less than would be obtained from established, offsite sources. Occasionally, such required excavation is marginal in suitability, so that a thorough subsurface investigation and documentation in a design memorandum may be needed. See Chapter 5 regarding sources at the project site.

3-4. Material Deterioration. An important axiom is that the same durability requirements are progressively more difficult to attain as the stone size requirement is increased. Problems with material characteristics can be manifested unexpectedly at the time the material is produced or later during exposure to environmental influences after placement. See Table 3-1 listing factors. Those material problems appearing at the time of production impact directly on realizing the design and are discussed in paragraph 3-5. Durability problems take any of several forms distinguished below. Despite their subjectivity, these modes facilitate descriptions and often suggest causative processes.

a. Cracking. The cracking phenomenon is characterized by the development within individual stones of one or more throughgoing cracks. Where a geological fabric such as bedding is present in the stones, the cracks usually propagate parallel or perpendicular to planar geological structures. In those stones where well-healed joints occur, it is common to find the cracking along these potentially weak surfaces.

b. Spalling. Spalling describes the special process of deterioration in which relatively thin shells break away from the stone surface. Corners and edges of stones are particularly vulnerable so that the stone evolves toward a rounded form. The whole process is observationally analogous to spalling of small, dried pieces of some shale or clay-rich rock upon immersion in water.

c. Delaminating or Splitting. Certain rock materials are prone to delaminating, slabbing, or splitting because of inherent geological structure. Many bedded sedimentary rocks and a few layered volcanic or metamorphic rocks separate preferentially along these geological features regardless of the cause of deterioration. This potential problem is widely recognized and most specifications for riprap and armor stone prohibit the inclusion of rocks containing prominent bedding, shaly layers, partings, or stylolites. In many cases, such materials are unavoidable within the constraints of costs or time schedule, and as a result, delaminating or splitting is among the most common forms of rock breakdown following project completion.

d. Disaggregating. Disaggregating can be a particularly severe problem. Disaggregating appears to be more likely to occur in clastic rather than crystalline rocks. In granular or clastic sedimentary rock, individual grains are sometimes held together only by a relatively weak cementing material. This characteristic is distinct from the intergrowth of component grains in crystalline rocks which provides a strengthening mechanical interlock. Disaggregation is manifested by continuing erosion, abrasion, or flaking away of increments of rock (near grain size) leading to stone rounding and reduction in size.

e. Dissolving. Occasionally, under unusual conditions such as emergencies, it has been necessary to use for temporary protection rock types susceptible to slow dissolution that were immediately available. Typical of such stone has been rock containing anhydrite.

f. Disintegrating. Characterization as disintegrating is reserved in this manual for application to cases of notably severe and rapid deterioration resulting from one or more of the processes in b. through e. above. Individual pieces are disintegrated leaving few or no traces of the original stones and making serious, though usually localized, deficiencies in the large-stone feature. Disintegration is rare today and usually involves only small fractions included with satisfactory rock during the quarrying operation.

3-5. Design Problems. Past design problems are briefly reviewed below. The discussion does not include those categories of problems unrelated to the characteristics of the material such as the common problem of deficiencies in the foundation of the structure.

a. Stone Size.

(1) The average weight of the stone is the primary design factor in gradation. Undersized stone, whether by inadequate specification or arising unexpectedly through deterioration from weathering, translates to design deficiencies. Undersized stone can translate into increased maintenance, premature repair or replacement, and occasional failure of the engineered feature. Some example problems related to size are displacement by wave or current action, ice plucking on lakes, and log gouging along streams.

(2) The design of a suitable gradation of material having a reasonable expectation of economical achievement can be a major effort in itself. Potential technical problems can range from a deleterious segregation of stone by sizes to difficulties in achieving rubble mass density and packing.

b. Stone Density. The average unit weight (loosely called density) of rock among individual stones is a design parameter usually causing few problems. Adequate density is of prime importance and receives high priority in evaluation of potential sources during planning and design investigations. However, complications occasionally arise, for example, among sedimentary strata which can vary in density from layer to layer across a quarry face. Where stratification or other variation presents problems, material sampling and testing need to be more comprehensive.

c. Stone Shape. Stone shapes or dimensional ratios are usually limited in specifications to 3:1 length to thickness. Although seldom explained in the past, this importance of stone shape converges from two directions. First, tabular shapes tend to be hydraulically less stable. Second, tabular shapes suggest geological fabric conducive to splitting to even thinner and smaller pieces. See paragraph 3-4c. regarding splitting behavior. Slabbiness may also be detrimental in rockfill applications. Large slabs tend to bridge and form large voids which may result in excessive settlement should the slabs break.

d. Bedding and Zoning. The interaction of large-stone features with adjacent elements of the completed structure can sometimes cause problems. For example, there may be a tendency for deleterious mixing of bedding stone into riprap or visa versa. The interfaces between zones in embankments may deserve similar careful consideration.

e. Foundation. Toe failures and erosional undercutting are problems related to the nature of the foundation, particularly where that foundation is soil rather than rock. Foundation problems are beyond the scope of this manual.

3-6. Construction Problems. Construction problems reflect the problems of economics, materials, and design, greatly intensified by the complexity of a major construction effort under contract. From the CE perspective, many problems are revealed as breakdowns in the inspection and control functions.

a. Material Acceptance. Costly problems have developed as a result of uncertainty or misunderstanding about the acceptability of stone or of a stone source. The wording of some specifications or listing of sources has been construed to have meant approval of material found subsequently to be inferior. Decisions in construction claims tend to show that a large burden rests on the CE staff to define clearly the limitations of materials and sources as a part of a contract.

b. Construction Quality Control. The contractor receives, handles, manipulates, and places the large-stone material with a considerable freedom in selection of equipment and methods. One or more of numerous problems can develop in this setting. For example, some large stone needs a period after quarrying in which to stabilize (paragraph 3-4c.). For reasons of delayed deliveries, such sensitive stone has occasionally been placed immediately following receipt, only to suffer cracking damage subsequently. The contractor quality control program, particularly its reporting function, can constitute the weakness or the strength in construction as explained in paragraph 8-2.

c. Construction Quality Assurance. The program of quality assurance (QA) provides the CE its principal way of minimizing problems during construction with large stone. Accordingly, ineffective inspection carries a share of responsibility for problems that do develop. As an example of a specific problem, a load of stone may be recognized as deficient in stone size and gradation, but the inspector is reluctant to reject it and require returning it to the source at the expense of the supplier. Sufficient provision for QA staffing will largely preclude instances of poor judgment.

3-7. Operations and Maintenance Problems. Problems arising during operations and maintenance usually reflect previous, latent or unrecognized problems. These problems can be correlated in many cases to poor stone characterization and selection processes during project design, and in other cases to construction activities. Regardless, periodic surveillance and evaluation by operations personnel of a project can identify time-dependent degradation of stone before the project is adversely impacted.